SUMMARY
OF
RESEARCH
1998

Department of Mathematics

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Chair

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Prepared for: Naval Postgraduate School
Monterey, CA 93943-5000

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NAVAL POSTGRADUATE SCHOOL
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13. ABSTRACT (Maximum 200 words.)

This report contains summaries of research projects in the Department of Mathematics. A list of recent publications is also included which consists of conference presentations and publications, books, contributions to books, published journal papers, technical reports, and thesis abstracts.

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DEPARTMENT OF MATHEMATICS
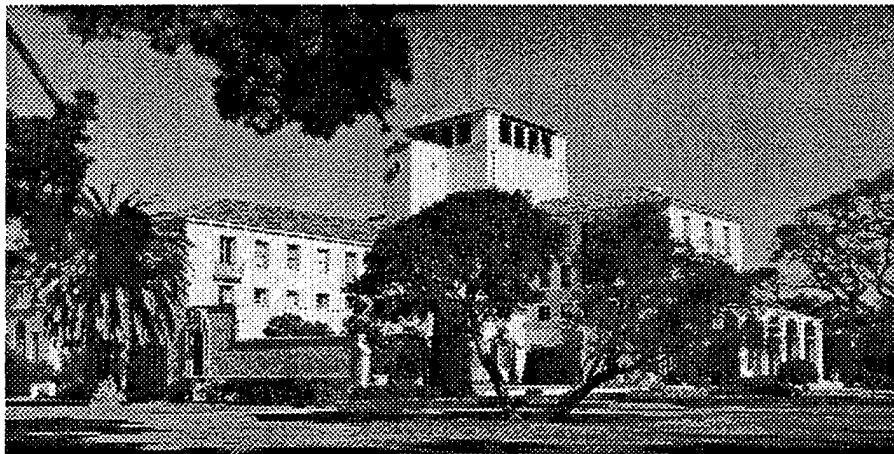
Guillermo Owen
Chair

THE NAVAL POSTGRADUATE SCHOOL MISSION

The mission of the Naval Postgraduate School is to increase the combat effectiveness of U.S. and Allied armed forces and enhance the security of the USA through advanced education and research programs focused on the technical, analytical, and managerial tools needed to confront defense-related challenges.

CONTENTS

PREFACE

Research at the Naval Postgraduate School is carried out by faculty in the School's eleven academic departments, seven interdisciplinary groups, and the School of Aviation Safety. This volume contains research summaries for the projects undertaken by faculty in the Department of Mathematics during 1998. Also included is an overview of the department, faculty listing, a compilation of publications/presentations, and abstracts from theses directed by the department faculty.

Questions about particular projects may be directed to the faculty Principal Investigator listed, the Department Chair, or the Department Associate Chair for Research. Questions may also be directed to the Office of the Associate Provost and Dean of Research. General questions about the NPS Research Program should be directed to the Office of the Associate Provost and Dean of Research at (831) 656-2099 (voice) or research@nps.navy.mil (e-mail). Additional information is also available at the RESEARCH AT NPS website, http://web.nps.navy.mil~code09/.

INTRODUCTION

The research program at the Naval Postgraduate School exits to support the graduate education of our students. It does so by providing militarily relevant thesis topics that address issues from the current needs of the Fleet and Joint Forces to the science and technology that is required to sustain the long-term superiority of the Navy/DoD. It keeps our faculty current on Navy/DoD issues, permitting them to maintain the content of the upper division courses at the cutting edge of their disciplines. At the same time, the students and faculty together provide a very unique capability within the DoD for addressing warfighting problems. This capability is especially important at the present time when technology in general, and information operations in particular, are changing rapidly. Our officers must be able to think innovatively and have the knowledge and skills that will let them apply technologies that are being rapidly developed in both the commercial and military sectors. Their unique knowledge of the operational Navy, when combined with a challenging thesis project that requires them to apply their focussed graduate education, is one of the most effective methods for both solving Fleet problems and instilling the life-long capability for applying basic principles to the creative solution of complex problems.

The research program at NPS consists of both reimbursable (sponsored) and institutionally funded research. The research varies from very fundamental to very applied, from unclassified to all levels of classification.

- Reimbursable (Sponsored) Program: This program includes those projects externally funded on the basis of proposals submitted to outside sponsors by the School's faculty. These funds allow the faculty to interact closely with RDT&E program managers and high-level policymakers throughout the Navy, DoD, and other government agencies as well as with the private sector in defense-related technologies. The sponsored program utilizes Cooperative Research and Development Agreements (CRADAs) with private industry, participates in consortia with other government laboratories and universities, provides off-campus courses either on-site at the recipient command or by VTC, and provides short courses for technology updates.

- NPS Institutionally Funded Research Program (NIFR): The institutionally funded research program has several purposes: (1) to provide the initial support required for new faculty to establish a Navy/DoD relevant research area, (2) to provide support for major new initiatives that address near-term Fleet and OPNAV needs, (3) to enhance productive research that is reimbursable sponsored, (4) to contribute to the recapitalization of major scientific equipment, and (5) to cost-share the support of a strong post-doctoral program.

- Institute for Joint Warfare Analysis (IJWA) Program: The IJWA Program provides funding to stimulate innovative research ideas with a strong emphasis on joint, interdisciplinary areas. This funding ensures that joint relevance is a consideration of research faculty.

In 1998, the overall level of research effort at NPS was 145 faculty workyears and exceeded $35 million. The Department of Mathematics' effort was 3.67 faculty workyears and reached almost $400,000. The sponsored research program has grown steadily to provide the faculty and staff support that is required to sustain a strong and viable graduate school in times of reduced budgets. In FY98, over 81% percent of the NPS research program was externally supported. In the Department of Mathematics 56% was externally supported.

The department's research sponsorship in FY98 is provided in Figure 1.
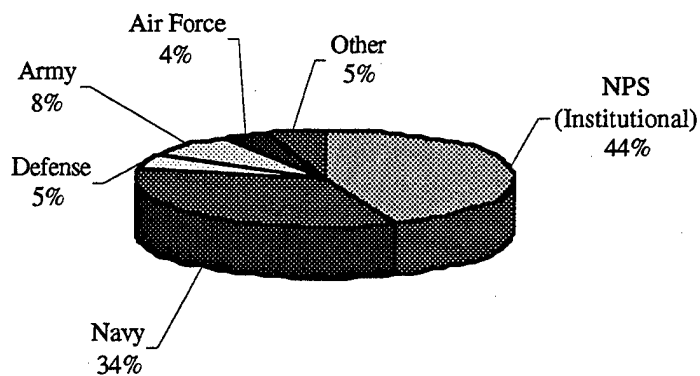
Figure 1. FY98 Sponsor Profile of the Department of Mathematics

These are both challenging and exciting times at NPS and the research program exists to help ensure that we remain unique in our ability to provide graduate education for the warfighter.

DAVID W. NETZER
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October 1999

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DEPARTMENT SUMMARY

Professor Borges' research was in two areas. First, the application of Markov Random Field models of texture to a variety of image processing problems. The main thrust of his work this year was on developing a practical set of computer algorithms to use as a toolbox in future investigations. Some additional studies of the appropriateness of MRF techniques for both image segmentation and target detection were also carried out. Professor Borges other main thrust concerned the development of fast and numerically stable algorithms for fitting polynomial splines to ordered data with minimal error in the total least-squares sense.

Professor Danielson's research is also in two areas. First, a collaborative effort with Professor Canright in to analyze the current version of NAVSPACECOM's AUTODC program for satellite orbits. The current code has flaws and is undocumented, precluding improvement. The investigators began their analysis and the development of complete documentation describing the mathematical algorithms and software structure of AUTODC.

Professor Danielson is also involved in collaborative effort in support of the ongoing development of the Army's RAH-66 Comanche helicopter. Research for 1998 comprised two parts: For the first part, developmental flight testing of the Comanche helicopter had revealed high vibrations caused by buffeting of the aircraft empennage. From the flight test aircraft differential pressure transducer and accelerometer data, the spectral content of the response was determined. Then, using a NASTRAN model of the aircraft, the frequency response functions between selected points on the aircraft's tail and the flight test accelerometer locations were calculated. Finally, various assumptions as to the location and distribution of empennage air loads were made, and the magnitude of these airloads, and the relative importance of primary airframe modal responses to these airloads, were determined. Efforts for the second half of 1998 were directed to a new area, that of designing the tailboom to withstand the high pressure blast emitted from a 23 mm HEI (High Explosive plus Incendiary) round.

Professor Franke was involved in several efforts. First was developing methods for approximating the vertical covariance function for temperature and moisture. Using a four-month history (March-June 1998) from NOGAPS the spatial covariance of the innovation data from temperature and relative humidity (respectively) were fit using eight different approximation schemes. Based on the results, two were chosen to use for extended investigations.

Professor Franke was also collaborated with Professors Neta and Clynch in an investigation of error in GPS positions. The error in GPS positions consists of two primary parts, a random error assumed to have a Gaussian distribution, and a slowly varying bias dependent upon the satellites from which the GPS receiver obtains its data and their configuration. The latter changes abruptly when a different configuration of satellites is used. The objective of this investigation is to devise techniques for estimating the two errors by using multiple trajectories obtained with GPS receivers in the Precise Position System along roads and then obtain an average trajectory.

Professor Fahroo was involved in several efforts as well. First, applying the theory of periodic optimal control to the problem of orbit control of low-Earth-orbiting (LEO) spacecraft and satellites, with the goal of finding optimal maneuvers that result in minimum fuel consumption. Her second project focused on determining the optimal location of controllers to achieve reduction of a noise field in an acoustic cavity. Finally, she continued her ongoing efforts to study the exponential stability of several acoustic-structure models by numerical approximation of the models.

Professor Gragg's research focused on implementing, rigorously testing, and proving numerical stability of new stable algorithms for executing the second phase of Pisarenko's signal processing algorithm, now reformulated so as to solve a well-conditioned problem. The new algorithms, stabilized forms of the unitary Hessenberg QR (uhqr) algorithm, permit fast, $O(n^2)$, solution of problems of (essentially) arbitrarily high order. Together, these algorithms provide algorithms for fast adaptive recursive least squares modeling of stationary time series by trigonometric polynomials (spectral estimation).

Professor Jayachandran continued his work on developing a statistical methodology for performing a sensitivity analysis of the project cost estimates produced by PACE, a computerized cost estimating model developed for the U.S. Coast Guard.

Professor Kang continued his work on bifurcations of control systems with uncontrollable dynamics. This year he developed a feedback design for the control of bifurcations with co-dimension one, and obtained the normal forms of systems with two uncontrollable modes are obtained. He also completed the design and simulations for the Moore-Greitzer model of engine compressors. This work has generated a great deal of very significant output.

Professor Mansager conducted ACQ 201 classes at Edwards AFB, CA; Philadelphia, PA; Jacksonville NAS, FL; Phoenix, AZ; and conducted a TST 301 at Warren, MI.

In addition to his joint work with Professor Franke mentioned above, Professor Neta was involved in several other research projects. First was an investigation of the possibility of a control decomposition approach to parallelize a numerical orbit. He was also involved in a collaboration with F.X. Giraldo wherein they analyzed the stability of the finite element approximation to the linearized two-dimensional advection-diffusion equation. Bilinear basis functions on rectangular elements are considered. Giraldo and Neta have previously numerically compared the Eulerian and semi-Lagrangian finite element approximation to the advection-diffusion equation. This work analyzes the finite element schemes used there.

Professor Rasmussen's work was in two main areas. First, an effort to develop and evaluate heuristics for finding approximate solutions to hard combinatorial optimization problems, such as graph coloring, that arise in diverse problems such as scheduling and frequency assignment. The focus in the past year was an improved implementation of an algorithm for approximating the chromatic number of a graph. Ada-95 code has now been developed, and tested, for a variety of key tasks (e.g., constructively determining the chromatic number of a chordal graph). His second research focus was the continuation of a collaborative project characterize competition graphs and p-competition graphs of various highly structured families of graphs and digraphs.

PRELIMINARY INVESTIGATION OF MARKOV RANDOM FIELD (MRF)
IMAGE SEGMENTATION FOR TACTICAL IMAGE COMPRESSION
Carlos F. Borges, Associate Professor
Department of Mathematics
Sponsor: Naval Engineering Logistics Office

OBJECTIVE: To investigate the application of MRF based image segmentation algorithms to tactical imagery, with special emphasis on possible application to the Radiant TIN algorithm.

SUMMARY: Several aspects of this problem were examined. The main focus was to generate good matching MRF texture for a variety of common textures in tactical imagery (e.g., asphalt). This effort began with the assembly of a select set of representative tactical imagery from a variety of sensors. After assembling a test set, the effort shifted to the recognition and generation of MRF textures. The current algorithms for accomplishing this task are very limited and a number of newer faster algorithms were created and tested. There is still a considerable amount of work remaining to get a complete toolbox of these algorithms but the preliminary results were promising.

DoD KEY TECHNOLOGY AREA: Other (Image Processing)

KEYWORDS: Image Compression, Markov Random Fields

AUTOMATIC TARGET DETECTION IN SYNTHETIC APERTURE RADAR (SAR)
IMAGERY USING MARKOV RANDOM FIELDS
Carlos F. Borges, Associate Professor
Department of Mathematics
Sponsor: Naval Postgraduate School

OBJECTIVE: To investigate the effectiveness of the Markov Random Field (MRF) paradigm as applied to automatic target detection in SAR imagery.

SUMMARY: This effort began with collecting a set of SAR images of known targets in different terrains. The imagery was analyzed under the assumption that the target regions were observations from a Markov Random Field with known structure. With this assumption it was possible to identify and classify targets in a cluttered background. Unfortunately, the available algorithms for working with MRFs are insufficient to make this technique useful at the current time. The main problems being insufficient speed for complex MRFs and the limited work on scale varying MRFs. However, it is clear that improved algorithms equal to the task could be developed given sufficient resources.

DoD KEY TECHNOLOGY AREA: Other (Image Processing)

KEYWORDS: Image Compression, Markov Random Fields

TOTAL LEAST SQUARES FITTING OF ORDERED DATA WITH POLYNOMIAL SPLINES
Carlos F. Borges, Associate Professor
Department of Mathematics
Sponsor: Unfunded

OBJECTIVE: To develop fast and numerically stable algorithms for fitting polynomial splines to ordered data with minimal error in the total least-squares sense.

SUMMARY: This unfunded effort is a continuing research project. The idea is to fit parametric polynomial spline curves to ordered data to get the best possible fit. Unlike traditional least-squares methods it was assumed that errors may occur in both the x and y directions. Moreover, the data is allowed to be completely general - in particular, it does not have to be functional in nature, it may overlap itself or change directions without restriction. All that is required is an ordered set of points in the plane. A variety of different approaches have been investigated and some very fast and robust algorithms have been developed for solving the problem for a single Bezier curve.

DoD KEY TECHNOLOGY AREA: Other (Scientific Computation)

KEYWORDS: Curve Fitting, Data Compression, Approximation Theory

NAVAL SPACE COMMAND DIFFERENTIAL CORRECTION PROGRAM ANALYSIS AND DOCUMENTATION

Don A. Danielson, Professor
David Canright, Associate Professor
Department of Mathematics
Sponsor: Naval Space Command

OBJECTIVE: The current version of NAVSPACECOM's AUTODC program for satellite orbits has flaws but is undocumented, precluding improvement. The proposed effort will obtain the source code of the AUTODC programs. These will be analyzed as to function. Complete documentation will be developed describing the mathematical algorithms and software structure of AUTODC. Portions of the AUTODC programs will be modified to run as stand-alone versions. These will be run and checked on NPS systems.

SUMMARY: The Fortran source code for AUTODC was obtained during a trip to the Naval Space Command. Several of the subroutines were analyzed and documented. Progress was made in documenting some of the other subroutines and the mathematical algorithms being used.

DoD KEY TECHNOLOGY AREA: Computing and Software

KEYWORDS: Satellites, Orbits, Computer Software

RESEARCH IN THE STRUCTURAL DYNAMIC RESPONSE OF THE RAH-66 COMANCHE HELICOPTER

Don A. Danielson, Professor
Department of Mathematics
E. Roberts Wood, Professor
Department of Aeronautics and Astronautics
Joshua H. Gordis, Associate Professor
Department of Mechanical Engineering
Sponsors: U.S. Army Comanche Program Office and Naval Postgraduate School

OBJECTIVE: Professors Wood, Danielson, and Gordis continued their work in support of the ongoing development of the Army's RAH-66 Comanche helicopter. Tasks included static and dynamic analyses. A dynamic NASTRAN finite element model provided the basis for the analyses and is maintained at NPS to support the ongoing Comanche flight test development program. The objective of the analyses is the optimization of the airframe for dynamic response.

SUMMARY: Research for 1998 comprised two parts: For the first part, developmental flight testing of the Comanche helicopter had revealed high vibrations caused by buffeting of the aircraft empennage. From the flight test aircraft differential pressure transducer and accelerometer data, the spectral content of the response was determined. Then, using a NASTRAN

model of the aircraft, the frequency response functions between selected points on the aircraft's tail and the flight test accelerometer locations were calculated. Finally, various assumptions as to the location and distribution of empennage air loads were made, and the magnitude of these airloads, and the relative importance of primary airframe modal responses to these airloads, were determined.

Efforts of the NPS Comanche team for the second half of 1998 were directed to a new area, that of designing the tailboom to withstand the the high pressure blast emitted from a 23 mm HEI (High Explosive plus Incendiary) round. For the new work, special software, MSC/DYTRAN is required. DYTRAN is a three dimensional code that is well suited for analyzing short, transient dynamic events that involve large deformations, a high degree of nonlinearity, and interactions between fluids and structures. Typical applications include: (1) response of structures to explosive and blast loading; (2) high-velocity penetration; and (3) weapons design calculations that involve self-forging fragments.

DYTRAN makes Lagrangian and Eulerian solvers available to enable modeling of both structures and fluids. Meshes within each solver can be coupled together to analyze fluid-structure interactions. Solid, shell, beam, membrane, spring, and rigid elements are used within the Lagrangian solver to model the structure, and the three-dimensional Eulerian elements can then be used in addition to create Eulerian meshes.

THESIS DIRECTED:

Mason, Patrick H., "Identification of Random Loads Impinging on the RAH-66 Comanche Helicopter Empennage Using Spectral Analysis," Master's Thesis, Naval Postgraduate School, June 1998.

DoD KEY TECHNOLOGY AREA: Air Vehicles

KEYWORDS: Helicopters, Airframe Dynamics, Random Aerodynamic Excitation, Dynamic Plasticity, Computer Software

NUMERICAL INVESTIGATION OF AN OPTIMAL PERIODIC CONTROL PROBLEM IN APPLICATION TO SPACE MANEUVERS
Fariba Fahroo, Assistant Professor
Department of Mathematics
Sponsor: Naval Postgraduate School

OBJECTIVE: To apply the theory of Optimal Periodic Control theory by numerical methods to the problem of orbit control of Low-Earth-Orbiting or LEO spacecraft.

SUMMARY: The purpose of this study was to apply the theory of periodic optimal control to the problem of orbit control of Low-Earth-Orbiting or LEO spacecraft and satellites. The goal was to find optimal maneuvers that would result in a minimum fuel consumption. In order to solve the problem, two different numerical techniques were considered: By the "Legendre Pseudospectral Method" the state, control, and the cost function were directly discretized. The optimal control problem was transformed to a Non-Linear Programming (NLP) problem and was solved. The other technique was an indirect method which numerically solved the state and co-state equations that are obtained by the application of Pontryagin Maximum Principle.

PUBLICATIONS:

Jensen, K., Fahroo, F., and Ross, I.M., "Application of Optimal Periodic Control Theory to the Orbit Reboost Problem," *Proceedings of the AAS/AIAA Space Flight Mechanics Meeting, Advances in the Astronomical Sciences Series,* Vol. 99, AAS Paper No. 98-16, February 1998.

Fahroo, F. and Ross, I.M., "Estimation of Co-States by a Legendre Pseudo-Spectral Method," *Proceedings of the 1998 AAIA GNC Conference,* Boston, MA, August 1998.

CONFERENCE PRESENTATIONS:

Jensen, K., Fahroo, F., and Ross, I.M., "Application of Optimal Periodic Control Theory to the Orbit Reboost Problem," AAS/AIAA Space Flight Mechanics Meeting, Monterey, CA, February 1998.

Fahroo, F. and Ross, I.M., "Estimation of Co-States by a Legendre Pseudo-Spectral Method," AAIA GNC Conference, Boston, MA, August 1998.

THESES DIRECTED:

Jensen, K., "Fuel Optimal Low Earth Orbit Maintenance," Master's Thesis, Naval Postgraduate School, June 1998.

DoD KEY TECHNOLOGY AREA: Space Vehicles

KEYWORDS: Co-State Estimation, Periodic Optimal Control Theory, Legendre Pseudo-Spectral Method, Low-Earth-Orbiting Spacecraft, Minimum Fuel Consumption

OPTIMAL LOCATION OF ACTUATORS FOR DISTRIBUTED PARAMETER SYSTEMS
Fariba Fahroo, Assistant Professor
Department of Mathematics
Sponsor: Unfunded

OBJECTIVE: The goal of this project was to develop a mathematical framework for finding the optimal location of controls and sensors for distributed parameter systems that arise in acoustic fields.

SUMMARY: In this project the focus was on the optimal location of controllers to achieve reduction of noise field in an acoustic cavity. The problem was first formulated as a linear quadratic tracking problem in a Hilbert space, and then the optimization problem was pursued as minimizing an appropriate performance criterion with respect to the location of the controls. Numerical examples were carried out to illustrate our theoretical results.

PUBLICATION:

Fahroo, F., "Optimal Placement of Controls for a One-Dimensional Active Noise Control Problem," *Kybernetika*, July 1998, accepted.

CONFERENCE PRESENTATION:

Demetriou, M. and Fahroo, F., "Optimal Location of Sensors and Actuators for Active Control of Acoustic Cavities," 1998 SIAM Control Conference, Jacksonville, FL, May 1998.

DoD KEY TECHNOLOGY AREA: Other (Active Noise Control)

KEYWORDS: Control of Distributed Parameter Systems, Active Noise Control, Optimization, Acoustics

NUMERICAL STUDY OF EXPONENTIAL STABILITY OF COUPLED FLUID/STRUCTURE SYSTEMS
Fariba Fahroo, Assistant Professor
Department of Mathematics
Sponsor: Unfunded

OBJECTIVE: To study the exponential stability of several acoustic-structure models by numerical approximation of these models. Convergence and stability of these numerical approximation are also studied.

SUMMARY: In this project a fluid-structure model was considered which consisted of a two dimensional air cavity and a vibrating flexible beam that formed a portion of the boundary of the cavity. A "porous" boundary condition was proposed for the beam equation which allowed the flow of air through the beam. The focus of the work was on establishing uniform exponential stability for the model, and to achieve this goal the multiplier technique was used which has already been used successfully in establishing exponential decay rates for wave equations with boundary feedback damping. After proving the desired stability result for the infinite-dimensional model, the effect was explored of choosing different boundary conditions on the stability of the model by performing numerous numerical simulations and also investigated different numerical schemes that would preserve the exponential stability of the original model under approximation.

PUBLICATION:

Fahroo, F. and Wang, C., "Numerical Experiments on Approximated Acoustic-Structure Systems," *Journal of Mathematical Systems, Estimation, and Control*, Vol. 8, No. 2, February 1998.

CONFERENCE PRESENTATION:

Fahroo, F., "Stability and Approximation of a Fluid-Structure Model," Conference on Control of Distributed Parameter and Stochastic Systems, Hangzhou, China, 19-22 June 1998.

DoD KEY TECHNOLOGY AREA: Other (Active Noise Control)

KEYWORDS: Exponential Stability, Acoustic-Structure Models, Numerical Approximations

VARIABLE VERTICAL RESOLUTION COVARIANCE FUNCTIONS FOR TEMPERATURE AND MOISTURE
Richard Franke, Professor
Department of Mathematics
Sponsor: Naval Research Laboratory-Monterey

OBJECTIVE: This investigation will develop methods for approximating the vertical covariance function for temperature and moisture. Navy Operational Global Atmospheric Prediction System (NOGAPS) data obtained from Naval Research Laboratory (NRL) will be used. The functions will be anisotropic and suitable for use in variable resolution models. Use of a domain transformation to obtain anisotropy is attractive because the positive definiteness properties of the approximation are naturally extended to the function on the original domain.

SUMMARY: Using a four-month history (March-June 1998) from NOGAPS the spatial covariance of the innovation data from temperature and relative humidity (respectively) were fit using eight different approximation schemes. Based on the results, two were chosen to use for extended investigations. The variances of forecast and observation errors were inferred in the usual way. The vertical correlation functions for temperature and for relative humidity errors were then fit using two different approximations coupled with a domain transformation. The cross-correlation of temperature and relative humidity errors were then inferred in two ways. First, by approximating the raw covariance data directly, and second by approximating the variance of the difference of normalized temperature and relative humidity innovation data. Again, two approxi-

mation methods were used in the two approaches. The latter approach was judged to be nominally superior to the first. The results are detailed in numerous figures and accompanying tables.

. **DoD KEY TECHNOLOGY AREAS:** Computing and Software, Modeling and Simulation

KEYWORDS: Numerical Weather Prediction, Data Assimilation, Covariance Functions, Objective Analysis

FAST, STABLE, COMPUTATIONAL ALGORITHMS FOR SPECTRAL DECOMPOSITION OF STATIONARY TIME SERIES
William B. Gragg, Professor
Department of Mathematics
Sponsor: Naval Postgraduate School

OBJECTIVE: To implement, rigorously test, and prove numerical stability of, new stable algorithms for executing the second phase of Pisarenko's signal processing algorithm, now reformulated so as to solve a well-conditioned problem. The new algorithms, stabilized forms of the unitary Hessenberg QR (uhqr) algorithm, permit fast, $O(n^2)$, solution of problems of (essentially) arbitrarily high order. To do the same for the related inverse algorithms (iuhqr). Together, these algorithms provide algorithms for fast adaptive recursive least squares modeling of stationary time series by trigonometric polynomials (spectral estimation).

SUMMARY: The first publication below describes the "stabilization" of the uhqr algorithm and gives rather massive numerical evidence that the tricks do their job. The paper has just appeared (1998). Mike Stewart (Australian National University) has already proved that (a very slight modification of) the scheme does its job. This is one of the trickiest rounding error analyses ever seen, and fortunately someone else did it. Mike is exceptionally expert at such matters and has asked for a collaboration on the other topics mentioned in the proposal, topics which could not be addressed due to lack of complete support of the project. A generalization of the uhqr algorithm, the last presentation below, permits, in principle, the $O(n^2)$ computation of all zeros of nth degree polynomials. Thus it solves a long-standing open problem of computational complex analysis. The details of implementation of a stable form of this algorithm will be decidedly nontrivial.

A paper was co-authored with Calvetti, Golub and Reichel on an elegant new algorithm for computing Gauss-Kronrod quadrature formulas, the second publication below. This uses techniques borrowed from the divide-and-conquer algorithm for the real symmetric tridiagonal eigenproblem.

PUBLICATIONS:

Gragg, William B., "Stabilization of the uhqr Algorithm," *Advances in Computational Mathematics,* Zhongying Chen, Yuesheng Li, Charles Micchelli, and Yuesheng Xu, (eds.), Lecture Notes in Pure and Applied Mathematics, Vol. 202, pp. 139-154, Marcel Dekker, Inc., Hong Kong, 1999.

Calvetti, D., Golub, G.H., Gragg, W.B., and Reichel, L., "Computation of Gauss-Kronrod Quadrature Formulas," *Mathematics of Computation,* to appear.

PRESENTATIONS:

Gragg, W.B., "Stabilization of the uhqr Algorithm," Conference on Applications and Computation of Orthogonal Polynomials, Mathematics Research Institute, Oberwolfach, Germany, 24 March 1998.

Gragg, W.B. and Calvetti, D., "Computation of Gauss-Kronrod Quadrature Rules," Conference on Applications and Computation of Orthogonal Polynomials, Mathematics Research Institute, Oberwolfach, Germany, 26 March 1998.

Gragg, W.B., "Stabilization of the uhqr Algorithm," 7th Conference of the International Linear Algebra Society, Madison, WI, 4 June 1998.

DoD KEY TECHNOLOGY AREA: Computing and Software

KEYWORDS: Pisarenko's Method, Signal Processing, Fast Algorithms, QR Algorithms, Unitary Hessenberg Matrices, Spectral Estimation, Stationary Time Series, Gauss-Kronrod Quadrature Formulas

DESIGN TOOLS TO ANALYZE COST ESTIMATES
Toke Jayachandran, Professor
Department of Mathematics
Sponsor: U.S. Coast Guard Research and Development Center

OBJECTIVE: To develop a statistical methodology for performing a sensitivity analysis of the project cost estimates produced by PACE, a computerized cost estimating model developed for the U.S. Coast Guard.

SUMMARY: The use of a power model such as the Cobb-Douglas Production function to represent the total cost of a project in terms of the component factor values is under examination. The use of mathematical/statistical techniques to estimate the change in the total cost when the factor values are perturbed is under investigation.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: Cost Estimation, Sensitivity Analysis

BIFURCATIONS OF CONTROL SYSTEMS WITH UNCONTROLLABLE DYNAMICS
Wei Kang, Assistant Professor
Department of Mathematics
Sponsor: Naval Postgraduate School

OBJECTIVE: (1) To develop a method of feedback design for the control of bifurcations with co-dimension one and co-dimension two. (2) To control the rotating stall and surge in gas engine compressors. (3) To test the performance robustness of submersible vehicles near the critical Froude number where pitchfork bifurcation occurs. (4) To enhance the research partnership of Mathematics Department with engineering departments of NPS in the fields involving analysis, design and scientific computation.

SUMMARY: A feedback design algorithm is developed for the control of bifurcations with co-dimension one. The normal forms of systems with two uncontrollable modes are obtained. Design and simulations are completed for the Moore-Greitzer model of engine compressors. Joint research with the Department of Aeronautics and Astronautics (Professor Isaac Kaminer) is initiated.

PUBLICATIONS:

Kang, W., "Bifurcation and Normal Form of Nonlinear Control Systems, Part I," *SIAM Journal Control and Optimization* 36, pp. 193-212, 1998.

Kang, W., "Bifurcation and Normal Form of Nonlinear Control Systems, Part II," *SIAM Journal Control and Optimization,* 36, pp. 213-232, 1998.

Fitch, O. and Kang, W., "Stabilization of a Class of Bifurcations by State Feedback," *Proceedings of the IEEE International Symposium on Circuits and Systems,* Monterey, CA, 31 May-3 June 1998.

Kang, W., Gu, G., Sparks, A., and Banda, S., "Bifurcation Test Functions and Surge Control for Axial Flow Compressors," *Automatica,* to appear.

CONFERENCE PRESENTATIONS:

Fitch, O. and Kang, W., "Stabilization of a Class of Bifurcations by State Feedback," IEEE International Symposium on Circuits and Systems, Monterey, CA, 31 May-3 June 1998.

Kang, W. and Krener, A.J., "Nonlinear Asymptotic Observer Design: A Backstepping Approach," MTNS98, Padova, Italy, 6-10 July 1998.

Gu, G., Sparks, A., and Kang, W., "Bifurcation Analysis and Control for Surge Model via the Projection Method," American Control Conference, Philadelphia, PA, 24-26 June 1998.

Kang, W., Xi, N., and Fitch, O., "Mobile Robot Tracking Control in a Perceptive Fram," SPIE, Boston, MA, 5-10 November 1998.

Kang, W. and Xi, N., "Sensor-Referenced Motion Planning and Dynamic Control for Mobile Robots," IEEE SMC, San Diego, CA, 12-14 October 1998.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Surface/Under Surface-Ships and Watercraft, Computing and Software

KEYWORDS: Bifurcation Control, Engine Compressor, Submersible Vehicle

PARALLEL VERSION OF SPECIAL PERTURBATION
Beny Neta, Professor
Department of Mathematics
Sponsor: U.S. Air Force Research Laboratory

OBJECTIVE: To develop a parallel version of a special perturbation code using task rather than data decomposition. This a continuation of work started last year. The serial version of the code is now installed and tested.

SUMMARY: Parallelization can be achieved by either control or domain decomposition. The latter was tried for analytic (by Neta, et al.), semianalytic (by Wallace) and numerical propagators (by Neal and Coffey). The control decomposition idea is inefficient for analytic propagators (Neta, et al.), because the computation time is too short. The possibility of a control decomposition approach to parallelize a numerical orbit propagator which is more computationally intensive was discussed.

PUBLICATIONS:

Neta, B. and Vallado, D., "On Satellite Umbra/Penumbra Entry and Exit Positions," *Journal of the Astronautical Sciences,* 46, pp. 91-103, 1998.

Neta, B., "Trajectory Propagation Using Information on Periodicity," *Proceeding of AIAA/AAS Astrodynamics Specialist Conference*, Boston, MA, Paper Number AIAA 98-4577, 10-12 August 1998.

Neta, B., "Parallel Version of Special Perturbations Orbit Propagator," Naval Postgraduate School Technical Report, NPS-MA-98-003, Monterey, CA, 1998.

CONFERENCE PRESENTATION:

Neta, B., "Trajectory Propagation Using Information on Periodicity," AIAA/AAS Astrodynamics Specialist Conference, Boston, MA, 10-13 August 1998.

ANALYSIS OF NUMERICAL SOLUTION OF PDEs
Beny Neta, Professor
Department of Mathematics
Sponsor: Unfunded

OBJECTIVE: To investigate the stability of the bilinear finite element approximation to the linearized two-dimensional advection-diffusion equation.

SUMMARY: The authors analyzed the stability of the finite element approximation to the linearized two-dimensional advection-diffusion equation. Bilinear basis functions on rectangular elements are considered. Giraldo and Neta have numerically compared the Eulerian and semi-Lagrangian finite element approximation to the advection-diffusion equation. This paper analyzes the finite element schemes used there.

PUBLICATION:

Giraldo, F.X. and Neta, B., "Stability Analysis for Eulerian and Semi-Lagrangian Finite Element Formulation of the Advection-Diffusion Equation," *Computers and Mathematics with Applications, An International Journal,* accepted for publication.

GPS TRAJECTORY AVERAGING
Beny Neta, Professor
Richard Franke, Professor
Department of Mathematics
James R. Clynch, Research Professor
Department of Oceanography
Sponsors: National Imagery and Mapping Agency and Naval Postgraduate School

OBJECTIVE: The error in GPS positions consists of two primary parts, a random error assumed to have a Gaussian distribution, and a slowly varying bias dependent upon the satellites from which the GPS receiver obtains its data and their configuration. The latter changes abruptly when a different configuration of satellites is used. The objective of this investigation is to devise techniques for estimating the two errors by using multiple trajectories obtained with GPS receivers in the Precise Position System along roads and then obtain an average trajectory.

SUMMARY: Numerous independent sets of data have been taken obtained. The steps in carrying out the required tasks are: partition sets of data into pieces that correspond to a particular part of a roadway and that have been taken using a single satellite configuration, select a portion of that path to be fit by a straight line or by a parametric cubic curve with continuous tangent vector, and compare the curves obtained for independent sets of data over the same path to estimate the bias vector between the two. When these steps are performed for many independent tracks an estimate of the true bias can be obtained. Matlab programs have been written that perform each of the above tasks.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: GPS, Bezier Curves, Bias Estimation, Curve Fitting, Track Averaging

COMPLETION-BASED HEURISTICS FOR INTRACTABLE GRAPH PROBLEMS
Craig W. Rasmussen, Associate Professor
Department of Mathematics
Sponsor: Naval Postgraduate School

OBJECTIVE: To develop and evaluate heuristics for finding approximate solutions to hard combinatorial optimization problems, such as graph coloring, that arise in diverse problems such as scheduling and frequency assignment. These problems are generally NP-complete, but typically are easily solved on certain families of highly structured problem instances. These families themselves possess more internal structure than was previously known, and the idea is to exploit this structure to obtain useful approximate solutions to the hard instances. More precisely, the idea is to accept as input a randomly generated graph G, locate a maximal chordal subgraph H of G, use H to initialize a completion algorithm that terminates when a chordal supergraph K of G is found. K is then assigned a coloring that is subsequently inherited by G.

SUMMARY: This summary covers the continuation of a project that was initiated in FY94 and which was partially funded by the Naval Postgraduate School in FY95-FY98. The focus during the period covered by this summary was improved implementation of an algorithm for approximating the chromatic number of a graph. Initially written in Matlab as part of a student's thesis project, the code suffered from incurable inefficiencies and was written in such a way that it resisted both validation and updating. Ada-95 code has now been developed, and tested, for the following tasks: (1) recognition of chordal graphs, which have good algorithmic properties; (2) construction of completion sequences of chordal graphs; (3) constructively determining the chromatic number of a chordal graph; and (4) random generation of graphs. Not yet implemented is code for location of a maximal chordal subgraph of an arbitrary input graph.

DoD KEY TECHNOLOGY AREA: Other (Applied Mathematics)

KEYWORDS: Chordal Graphs, Graph Coloring

p-COMPETITION GRAPHS: CHROMATIC PROPERTIES AND CHARACTERIZATIONS
Craig W. Rasmussen, Associate Professor
Department of Mathematics
Sponsor: Unfunded

OBJECTIVE: Characterize competition graphs and p-competition graphs of various highly structured families of graphs and digraphs.

SUMMARY: This is ongoing work that is conducted jointly with colleagues at CU-Denver, Kenyon College, and the University of the Pacific. The project is an outgrowth of a project that was supported during FY93 and FY94 by NPS. A related area is that of upper-bound graphs of posets. Joint work in that area is with the Denver group and with a colleague at the University of Louisville.

PUBLICATION:

Rasmussen, C.W., Lundgren, J.R., Mckenna, P.A., and Merz, S.K., "p-Competition Graphs of Symmetric Digraphs and p-Neighborhood Graphs," *Journal of Combinatorics, System and Information Sciences*, 22, No. 2, 1997. (Publication delayed until 1998.)

DoD KEY TECHNOLOGY AREAS: Computing and Software, Other (Resource Allocation)

KEYWORDS: Ordered Sets, Chordal Graphs, Interval Graphs

PUBLICATIONS/PRESENTATIONS

JOURNAL PAPERS

Borges, C.F. and Frezza, R., "Models of Gaussian Reciprocal Processes and Periodic Jacobi Matrices," *Journal of Mathematical Systems, Estimation, and Control*, Vol. 8, No. 1, January 1998.

Canright, D. and Beaver, P., "The Quasimonotonicity of Linear Differential Systems," *Applicable Analysis*, Vol. 70, 1-2, pp. 67-73, October 1998.

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Kang, W., "Bifurcation and Normal Form of Nonlinear Control Systems Part I," *SIAM Journal Control and Optimization*, 36, pp. 193-212, 1998.

Kang, W., "Bifurcation and Normal Form of Nonlinear Control Systems Part II," *SIAM Journal Control and Optimization*, 36, pp. 213-232, 1998.

Neta, B. and Vallado, D., "On Satellite Umbra/Penumbra Entry and Exit Positions," *Journal of the Astronautical Sciences*, 46, pp. 91-103, 1998.

Rasmussen, C.W., Lundgren, J.R., Mckenna, P.A., and Merz, S.K., "p-Competition Graphs of Symmetric Digraphs and p-Neighborhood Graphs," *Journal of Combinatorics, System, and Information Sciences*, 22, No. 2, 1998.

CONFERENCE PAPERS

Fahroo, F. and Ross, I.M., "Estimation of Co-States by a Legendre Pseudo-Spectral Method," *Proceedings of the 1998 AAIA GNC Conference*, Boston, MA, August 1998.

Fitch, O. and Kang, W., "Stabilization of a Class of Bifurcations by State Feedback," *Proceedings of the IEEE International Symposium on Circuits and Systems*, Monterey, CA, 31 May-3 June 1998.

Neta, B., "Trajectory Propagation Using Information on Periodicity," *Proceeding of AIAA/AAS Astrodynamics Specialist Conference*, Boston, MA, Paper Number AIAA 98-4577, 10-12 August 1998.

Jensen, K., Fahroo, F., and Ross, I.M., "Application of Optimal Periodic Control Theory to the Orbit Reboost Problem," *Proceedings of the AAS/AIAA Space Flight Mechanics Meeting, Advances in the Astronomical Sciences Series*, Vol. 99, AAS Paper No. 98-16, February 1998.

CONFERENCE PRESENTATIONS

America, J., Broadwater, J., and Mansager, B.K., "High Resolution Recreations of Historical Special Operations Case Studies," 66th MORS Symposium, Monterey, CA, June 1998.

Demetriou, M. and Fahroo, F., "Optimal Location of Sensors and Actuators for Active Control of Acoustic Cavities," 1998 SIAM Control Conference, Jacksonville, FL, May 1998.

Fahroo, F. and Ross, I.M., "Estimation of Co-States by a Legendre Pseudo-Spectral Method," AAIA GNC Conference, Boston, MA, August 1998.

PUBLICATIONS/PRESENTATIONS

Fahroo, F., "Stability and Approximation of a Fluid-Structure Model," Conference on Control of Distributed Parameter and Stochastic Systems, Hangzhou, China, 19-22 June 1998.

Fitch, O. and Kang, W., "Stabilization of a Class of Bifurcations by State Feedback," IEEE International Symposium on Circuits and Systems, Monterey, CA, 31 May-3 June 1998.

Gragg, W.B., "Stabilization of the uhqr Algorithm," Conference on Applications and Computation of Orthogonal Polynomials, Mathematics Research Institute, Oberwolfach, Germany, 24 March 1998.

Gragg, W.B. and Calvetti, D., "Computation of Gauss-Kronrod Quadrature Rules," Conference on Applications and Computation of Orthogonal Polynomials, Mathematics Research Institute, Oberwolfach, Germany, 26 March 1998.

Gragg, W.B., "Stabilization of the uhqr Algorithm," 7th Conference of the International Linear Algebra Society, University of Wisconsin, Madison, WI, 4 June 1998.

Gu, G., Sparks, A., and Kang, W., "Bifurcation Analysis and Control for Surge Model via the Projection Method," American Control Conference, Philadelphia, PA, 24-26 June 1998.

Jensen, K., Fahroo, F., and Ross, I.M., "Application of Optimal Periodic Control Theory to the Orbit Reboost Problem," AAS/AIAA Space Flight Mechanics Meeting, Monterey, CA, February 1998.

Kang, W. and Krener, A.J., "Nonlinear Asymptotic Observer Design: A Backstepping Approach," MTNS98, Padova, Italy, 6-10 July 1998.

Kang, W., Xi, N., and Fitch, O., "Mobile Robot Tracking Control in a Perceptive Fram," SPIE, Boston, MA, 5-10 November 1998.

Kang, W. and Xi, N., "Sensor-Referenced Motion Planning and Dynamic Control for Mobile Robots," IEEE SMC, San Diego, CA, 12-14 October 1998.

Neta, B., "Trajectory Propagation Using Information on Periodicity," AIAA/AAS Astrodynamics Specialist Conference, Boston, MA, 10-13 August 1998.

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Neta, B., "Parallel Version of Special Perturbations Orbit Propagator," Naval Postgraduate School Technical Report, NPS-MA-98-003, Monterey, CA, 1998.

Russak, I. Bert and Jayachandran, Toke, "Removal of the Assumption of Cellular Targets in Computing Damage Aggregation to an Area Target from a Salvo of N Weapons," Naval Postgraduate School Technical Report, NPS-MA-98-001, December 1997.

Scandrett, Clyde L., "Fluid Structure Interactions," Naval Postgraduate School Technical Report, NPS-MA-98-002, December 1997.

AN IMPLEMENTATION OF SECURE FLOW
TYPE INFERENCE FOR A SUBSET OF JAVA

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B.S., Turkish Naval Academy, 1992
Master of Science in Computer Science-September 1998
Advisor: Dennis Volpano, Department of Computer Science
Second Reader: Craig Rasmussen, Department of Mathematics

Smart cards play an important role in a digital society. A smart card contains memory or an embedded microprocessor with the capability of enabling a wide variety of services, such as electronic cash in the case of memory cards and digital signature computation in the case of processor cards. A processor card can require a cardholder to authenticate herself in order to prevent others from using the card's services, from forging the cardholder's signature, for example. Authentication can be done by storing a personal identification number (PIN) or digitized fingerprint of the cardholder on the card itself. The PIN or fingerprint must always remain confidential no matter how the card is (ab)used.

This thesis addresses the problem of preserving the privacy of information stored on smart cards. Volpano and Smith have developed a static analysis for analyzing source code for information flow violations. This technique is developed further here for a language called Java Card, in which smart card applications are written. A prototype analyzer is presented for a subset of Java Card and applied to a sample card application to demonstrate its utility in protecting private information stored on smart cards.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Other (Smart Cards, Software Security, Type System)

KEYWORDS: Java Card, Smart Cards, Secure Flow Analysis, Type System

ON THE QUASIMONOTONICITY OF A SQUARE LINEAR OPERATOR
WITH RESPECT TO A NONNEGATIVE CONE

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M.S., Naval Postgraduate School, 1991
Doctor of Philosophy in Applied Mathematics-June 1998
Advisor: David Canright, Department of Mathematics
Committee: Christopher L. Frenzen, Department of Mathematics
Robert F. Dell, Department of Operations Research
Clyde L. Scandrett, Department of Mathematics
Maurice D. Weir, Department of Mathematics

The question of when a square, linear operator is quasimonotone nondecreasing with respect to a nonnegative cone was posed for the application of vector Lyapunov functions in 1974. Necessary conditions were given in 1980, which were based on the spectrum and the first eigenvector. This dissertation gives necessary and sufficient conditions for the case of the real spectrum when the first eigenvector is in the nonnegative orthant, and when the first eigenvector is in the boundary of the nonnegative orthant, it gives conditions based on the reducibility of the matrix. For the complex spectrum, in the presence of a positive first eigenvector the problem is shown to be equivalent to the irreducible nonnegative inverse eigenvalue problem.

DoD KEY TECHNOLOGY AREA: Other (Applied Mathematics)

KEYWORDS: Quasimonotonicity, Nonnegative Cone

THE UTILITY OF THE ADVANCED SEAL DELIVERY SYSTEM (ASDS) (U)

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Master of Science in Defense Analysis-June 1998
Master of Science in Management-June 1998
Advisors: Gordon H. McCormick, Special Operations /Low Intensity Conflict Curriculum Committee
Bard Mansager, Department of Mathematics

The United States Special Operations Command (USSOCOM) is in the process of procuring the Advanced SEAL Delivery System (ASDS), a mini-submersible, to be used by Naval Special Warfare (NSW) forces to conduct maritime special operations. During the development of the ASDS, costs have more than doubled. Consequently, USSOCOM is reevaluating the future of ASDS. This thesis assesses the utility of the ASDS by viewing the ASDS as a part of an "infiltration system" and analyzing the linkages and fit of ASDS within the strategic framework in which it is intended to operate. Modeling the primary factors that define ASDS as a viable special operations platform in high, medium, and low threat environments does this. The output of the model is the capability of ASDS expressed in terms of "mission success." The estimated annual cost of ASDS is also calculated using the current acquisition strategy. In order to compare against current capabilities and their respective costs, this process is repeated for four alternative NSW infiltration systems. Although the ASDS has the highest cost, it is the only system that presents an acceptable probability of mission success in high and medium threat environments. Given NSW's strategic framework, the ASDS has a high utility.

DoD KEY TECHNOLOGY AREAS: Surface/Undersurface Vehicles-Ships and Watercraft, Modeling and Simulation

KEYWORDS: Advanced SEAL Delivery System, Mini-Submersible, ASDS, NSW, USSOCOM, Mission Success

MATRIX ALGEBRA

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Master of Science in Applied Mathematics-June 1998
and
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Master of Science in Applied Mathematics-June 1998
Advisors: Carlos F. Borges, Department of Mathematics
Craig W. Rasmussen, Department of Mathematics

This thesis is designed to act as an instructor's supplement for the Naval Postgraduate School's (NPS) refresher matrix algebra courses. The need for a beginning matrix algebra supplement is driven by the unique circumstances that a majority of NPS students find themselves. Most military students attend NPS several years after receiving their undergraduate degrees. This supplement, unlike most college textbooks, bridges the gap between the student's educational lay-off and the rigors of mathematically oriented degrees such as applied math, operations research and engineering. By reviewing the fundamental concepts of vectors and matrices, and computationally performing operations on them, the student quickly develops the requisite knowledge to succeed in NPS' demanding curriculums. This supplement focuses on matrix and vector operations, linear transformations, systems of linear equations, and the techniques required to computationally solve systems of linear equations. The goal of this thesis is to enhance current textbooks and help the beginning student in matrix algebra in order to build a foundation for higher level engineering and mathematics based courses.

DoD KEY TECHNOLOGY AREA: Other (Matrix Algebra Supplement)

KEYWORDS: Matrix Algebra

CHANNEL ALLOCATION IN WIRELESS INTEGRATED SERVICES
FUEL-OPTIMAL LOW-EARTH-ORBIT MAINTENANCE

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Aeronautical and Astronautical Engineer, Naval Postgraduate School-June 1998
Advisors: I. Michael Ross, Department of Aeronautics and Astronautics
Fariba Fahroo, Department of Mathematics

First-order solutions indicate that a forced Keplerian trajectoiy (FKT) obtained by thrust-drag cancellation is as fuel-efficient as a Hohmann transfer. Further analysis has shown that the FKT is not Mayer-optimal. Therefore, there must exist another trajectory that matches or exceeds the efficiency of the Hohmann transfer. The application of this result to the fuel-optimal orbit maintenance problem implies that periodic reboosts must be more efficient than an FKT profile. This research begins with the formulation of an optimal periodic control (OPC) problem to determine the minimum fuel-reboost strategy. The problem is numerically solved by a spectral collocation method. The optimization code is further modified to increase accuracy and reduce sensitivity to initial guesses. The results of this effort identified a trajectory for a sample satellite that was 3.5% more efficient than an ideal impulsive Hohmann transfer over the same period of time. From the optimal code, a maximum thruster size is also identifiable for a set of initial conditions. The optimal trajectory can save as much as 10% of the propellant budget when compared to finite-bum Hohmann transfers.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power, Space Vehicles, Modeling and Simulation

KEYWORDS: Orbital Maintenance, Orbital Mechanics, Hohmann Transfer, Orbit Reboost, Orbit Transfer, Forced Keplerian Trajectory, Optimization, Periodic Control

IDENTIFICATION OF RANDOM LOADS IMPINGING ON THE RAH-66
COMANCHE HELICOPTER EMPENNAGE USING SPECTRAL ANALYSIS

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Donald A. Danielson, Department of Mathematics
Joshua H. Gordis, Department of Mechanical Engineering

The Army RAH-66 Comanche Helicopter is currently undergoing developmental flight testing. The empennage of the aircraft is experiencing buffeting where the horizontal and vertical tail vibrate at resonant frequencies. These high buffet loads are manifested in higher than anticipated fitting loads, particularly on the tail, and vibrations in the crew stations and at the nose cone where the targeting sensors are located. Significant effort has been devoted to identifying the sources of excitation and the nature of the structural response. This thesis determines the location and magnitude of empennage vibratory airloads. Because the nature of the excitation is a random function, spectral analysis is used. To obtain the loads, a three-step process was utilized. First, from aircraft differential pressure transducers and accelerometers, the spectral content of the response and excitation was determined Then, using a NASTRAN model modified to replicate the flight test aircraft, frequency response functions were determined between selected points on the aircraft's tail and the accelerometers. Finally, using this information, a solution was obtained for the vibratory airloads. Having provided information on the nature of the driving forces, structural modifications can be made that move the natural frequencies away from the frequencies of the applied airloads.

DoD KEY TECHNOLOGY AREA: Air Vehicles

KEYWORDS: RAH-66 Comanche Helicopter, Random Vibrations, Comanche Tail Section, Structural Analysis, Spectral Analysis, NASTRAN Analysis

AN EXAMINATION OF BI-ORTHOGONALITY RELATIONSHIPS
IN ELASTIC-FLUID MEDIA

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Christopher L. Frenzen, Department of Mathematics

The bi-orthogonality relationships for vertically heterogeneous porous media in contact with various surfaces have been previously established. For the special case in which the porous substance has zero porosity, the relationships reduce to those for elastic media. The biorthogonality relationship for a fluid loaded elastic slab will be considered numerically by discritizing the boundary value problems using finite differences. The resulting matrix will be analyzed for the purpose of determining eigenvalues of the complex dispersion relationship of the layered media, as well as discerning the corresponding eigenvectors which are discrete analogies of the propagation/evanescent eigenfunctions of the media.

DoD KEY TECHNOLOGY AREA: Other (Acoustics, Mathematics)

KEYWORDS: Acoustics, Bi-orthogonality, Elasticity

AN EXPERIMENTAL INVESTIGATION OF VORTEX
BREAKDOWN IN TUBES AT HIGH REYNOLDS NUMBERS

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M.S., Naval Postgraduate School, 1992
M.E., Naval Postgraduate School, 1992
Doctor of Philosophy in Mechanical Engineering-September 1998
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Committee: Matthew Kelleher, Department of Mechanical Engineering
F. Kevin Owen, Department of Mechanical Engineering
David Netzer, Department of Aeronautics and Astronautics
Richard Franke, Department of Mathematics

This thesis deals with non-cavitating swirling flows with vortex breakdown in various tubes. Phenomenological and quantitative investigations were carried out at Reynolds numbers ($Re_D = U_0 D_0/n$) as high as 300,000. It was shown that a high Re_D vortex transitions to its new state (breaks down) via a rapidly spinning spiral form, as demonstrated with 4,000 frame per second video, short exposure time (6 ns) imaging, and Digital Particle Image Velocimetry. Of the known types, the spiral emerges as the fundamental breakdown form, and the axisymmetric bubble may now be regarded as a relatively low Re_D occurrence that is bypassed at sufficiently high Re_D. Some new phenomena were observed at high Re_D: Extremely rapid spiral rotation (over 1,000 revolutions per second), core bifurcation, and reversals in the sense of the spiral windings. Familiar features of breakdowns, such as the transition from jet-like to wake-like axial velocity profiles and the rapidly expanding vortex core, were observed in extensive time averaged velocity and turbulence profiles ascertained with Laser Doppler Velocimetry. However, a mean stagnation point and recirculation were absent in the highest Re_D flow. The core meandering and stagnation point darting in the turbulent flow field were quantified and discussed in detail.

DoD KEY TECHNOLOGY AREA: Air Vehicles

KEYWORDS: Vortex Breakdown, Turbulence, Laser Doppler Velocimetry, Particle Image Velocimetry, Swirling Flow, Spectra

BIZIER CURVE FITTING

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Second Reader: Richard Franke, Department of Mathematics

We typically think of fitting data with an approximating curve in the linear least squares sense, where the sum of the residuals in the vertical, or y, direction is minimized. The problem addressed here is to fit a BJzier curve to an ordered set of data in the total least squares sense, where the sum of the residuals in both the horizontal and vertical directions is minimized. More exact: given an ordered set of m data points d_i, $i'1,2,^,m$ find a set of control points b_i, $i'0,1,^,n$ where n is the order of the BJzier curve, and a vector t of nodes, $0 \# t_1 \# t_2 \# _ \# t_m \# 1$ that minimize $\| B(t)P - D \|_F$. The matrix D contains the data points, the matrix P contains the control points, and the matrix $B(t)$ is a Bernstein matrix. The algorithm to accomplish this is explained in detail and makes extensive use of the linear algebra representation of BJzier curves.

DoD KEY TECHNOLOGY AREA: Other (Applied Mathematics)

KEYWORDS: BJzier Curves, Gauss-Newton Method, Affine Invariant Node Spacing

NAVY SEALS: THEORY VS. REALITY

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Second Reader: Bard K. Mansager, Department of Mathematics

The purpose of this thesis is to examine two books that advance alternate theories to explain the success or failure of special operations. The first book is *Perilous Options: Special Operations as an Instrument of U.S. Foreign Policy*, by Lucien S. Vandenbroucke. Vandenbroucke discusses recurrent problems with U.S. special operations and identifies what he believes are the causes of failure of such operations. The second book is *Spec Ops*, written by William H. McRaven. McRaven examines eight historic cases from around the globe and develops his theory on how to conduct successful special operations. From the analysis of three recent Navy SEAL's special operations missions, both theories seem to provide a useful tool for thinking about the failure or success of special operations. Combining these theories provides a complete framework for senior planners and tacticians in formulating a plan for successfully conducting future special operations missions.

KEYWORDS: SEALs, Urgent Fury, Just Cause, Desert Storm

DoD KEY TECHNOLOGY AREA: Other (Special Operations)

DEVELOPMENT OF A TEST MECHANISM FOR ANALYZING FORCE ATTRITION METHODOLOGIES WITHIN AGGREGATED COMBAT SIMULATIONS

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Master of Science in Applied Mathematics-June 1998
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James G. Taylor, Department of Operations Research

For aggregated combat simulation models, the methods for calculating force attrition must be based upon sound mathematical formulations and parameter estimations. With an inherent lack of representative combat data for modern warfare scenarios, one effective method for determining the required parameter estimates is to thoroughly analyze the output from a

stochastically based high-resolution combat model. It is this development of attrition parameters process, which so profoundly influences the validity of aggregated simulations, that lacks any comprehensive documentation or mathematical justification within the modeling community. By examining the development and validity of these processes for parameter estimation, valid attrition calibration formulae can be determined and used within force attrition algorithms in order to more precisely and justifiably model aggregated combat operations. The establishment of a user-friendly test bed for examining this attrition rate development process will play a major role in solidifying the understanding, implementation, and validation of current and future process techniques.

DoD KEY TECHNOLOGY AREA: Modeling and Simulation

KEYWORDS: Combat Modeling, JANUS, Simulation, Attrition, ATCAL

NETWORKS FOR LOW-BIT-RATE APPLICATIONS

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This work addresses issues related to the design and performance of a wireless integrated services network with emphasis on a tactical framework. We propose an asynchronous transfer mode (ATM)-like protocol architecture for the mobile network, which is an extension of schemes proposed in the literature. A medium-access-control (MAC) scheme, based on slot reservation by the remotes, is proposed for the network. Traffic models for low-bit-rate applications, suitable for low-capacity channels, such as a multiple-access (macrocell) wireless network, are presented. New bi-directional speech-conversation and bursty data models are proposed.

The issue of scheduling in wireline integrated services networks is thoroughly addressed and new algorithms are proposed. An analytical scheme to obtain the required (static) capacity for homogeneous sources based on their Markov-chain characterization is provided. A necessary condition for optimality of a scheduling algorithm is the balance of cell-loss-probability (CLP) ratios to values approaching 1 from below, on the boundary of the admissible region. The balanced-CLP-ratio (BCLPR) algorithm satisfies this condition but ignores the deadlines of the cells. The shortest time to extinction (STE) with BCLPR (STEBR) algorithm, proposed here for the first time, utilizes the earliest-deadline-first concept while satisfying the necessary condition. A proof is provided to show that the STEBR decisions are optimal at each service slot given that no information about future traffic arrivals is available. Simulation results indicate that STEBR admits more sources and yields larger normalized channel throughput (by up to 4%) than STE.

The wireless network presents a case of distributed queues at the command post (CP) and in the remotes, making channel allocation more involved compared to scheduling in wireline systems. Based on the schedulers discussed for the wireline queue, corresponding algorithms for operation in the wireless network are developed. The cases of partial and complete status reports of the remotes are investigated as a function of the network load in five representative scenarios. The following (descending) order of performance under both partial and complete status reports is maintained in all scenarios:STEBR, STE, BCLPR, and static allocation. Performance of the schedulers using partial or complete status reports depends on the value of the normalized throughput. The complete-status mechanism is preferred whenever the normalized throughput is smallerthan 0.70-0.75; partial status reports are sufficient for normalized throughput larger than 0.70-0.75. A hybrid approach that makes use of this outcome is proposed to best utilize the available channel capacity under all possible levels of network load.

DoD KEY TECHNOLOGY AREA: Command, Control, and Communications, Modeling and Simulation, Other (Networking)

KEYWORDS: B-ISDN, ATM, MAC, Scheduling, Channel Allocation, Mobile Networks, Low-Bit-Rate Source Models

APPLICATIONS OF JOINT TACTICAL SIMULATION MODELING

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Advances in technology allow Computer Simulation Models (CSM) to be used as a powerful tool to aid military decision-makers. This thesis explores the usefulness of one of these models, the Joint Tactical Simulation (JTS). First, this thesis outlines the information and tasks required to run JTS, which will give the reader a basic understanding of the program and how much effort it requires. Next, it describes the scenario presented in this thesis by detailing the methodology of terrain development, listing the assets required and the mission concept employed. It concludes by discussing some of the advantages and disadvantages of JTS followed by a reevaluation of the simulation and its possible uses.

The concluding appendix is a tutorial that guides the reader through an amphibious assault modeled on the UNIX-based computer systems at the Naval Postgraduate School's (NPS) Secure Systems Technology Laboratory. It was designed to be accomplished in less than four hours and give the user an opportunity to run a simulation while conducting minimal interaction.

KEYWORDS: Joint Tactical Simulation, Naval Special Warfare, High Resolution Models

DoD TECHNOLOGY AREA: Modeling and Simulation

SOLUTION OF LARGE-SCALE ALLOCATION PROBLEMS WITH PARTIALLY OBSERVABLE OUTCOMES

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Methods were developed for optimally solving problems that require allocating scarce resources among activities that either gather information on a set of objects or take actions to change their status. Also, the information gathered on the outcomes of the actions taken may be erroneous. The latter situation is called *partial observability*, and methodology available prior to this dissertation is combinatorially intractable for problems with more than one object. Two previously-uncombined methods were used–linear programming (LP) and partially observable Markov decision processes (POMDPs) – to construct a decomposition procedure to solve the resulting large-scale allocation problem with partially observable outcomes. Theoretically it was shown that this procedure is both optimal and finite; in addition, improvements were developed to the procedure that reduce runtimes on test problems by 95%. It was demonstrated that the procedure on a small targeting problem with a known analytical solution, as well as a large-scale military example concerned with allocating aircraft sorties, weapons, and bomb-damage assessment sensors to targets. Finally, analytical bounds were developed on the expected objective function values of a related allocation problem with more stringent resource constraints, and present a simulation-based approach to estimate the distributions of the outcomes for that model.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Command, Control, and Communications, Conventional Weapons, Sensors, Modeling and Simulation, Materials, Processes, and Structures

KEYWORDS: POMDP, MDP, Linear Programming, USAF, BDA, Sensor Modeling

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